SI-00-1

Central Baryons in Dual Models and the Possibility of a Backward Peak in Diffraction

Fritz W. Bopp

Universität Siegen, Fachbereich Physik,
D–57068 Siegen, Germany

February 7, 2008

Abstract

Two distinct interactions of Pomerons should occur in dense multi-string events. Besides the usual triple Pomeron processes transitions to membraned cylinders can be expected to contribute in a significant way. They offer an efficient mechanism for central baryon production and for the long range transport of initial baryons. The slope of such an exchange should be quite low as it is related to the Odderon known from the leading logarithmic approximation. Such a flat trajectory has to be suppressed by small coupling constants. It is argued that this strong suppression does not appear in diffractive events. In consequence there should be a tiny observable backward peak in the initial baryon distribution even in quite massive diffractive systems.

1 Introduction

In heavy ion collisions the stopping of incoming baryons is stronger than expected from a simple superposition of nucleon reactions. A number of mechanisms were introduced in a somewhat ad hoc way to repair this shortcoming and to enhance the slowing-down of baryons in heavy ion collisions[1, 2, 3, 4] and no real problem seems to remain[1, 5]. The aim of the present work is to better understand the basic mechanism.

In Topological models there is a definite mechanism which drastically increases the slowing-down of baryons in heavy ion reactions. Besides the cylinder of the conventional Pomeron scattering a membraned cylinder should appear. It could have a significant effect on the overall event structure in dense scattering processes. Just like the Pomeron it can be understood as a soft extrapolation of a known hard QCD exchange. If observed this second example of a connection between a soft and a hard object would be of considerable theoretical interest.

Unfortunately there is a large quantitative uncertainty. The relevant slope parameter is not sufficiently constrained by existing baryon exchange data to allow definite conclusions about the expected weight of this new contribution. However, there is a very specific effect in diffractive final states and possibly in electro-production. The existence of such a contribution can therefore be tested and its weight is accessible to direct experimental observation.

After a short excursion to hadron hadron scattering we will consider heavy ion reactions and discuss the proposed mechanism of baryon transport in this context. We will then turn to general consequences including the clear cut backward scattering peak in diffractive events.

2 Baryon transfer in particle scattering

Available experimental data To observe the slowing down of the incoming baryon charge to central or opposite rapidities, one needs to somehow identify the incoming contribution to the baryon spectra. It is usually assumed that the produced baryons and anti-baryons have identical distributions. A simple subtraction then provides the desired initial baryon distribution. This trick does not work for proton antiproton scattering, where the sea-baryon contribution cannot be determined from data without model assumptions. Unfortunately this precludes the use of post ISR data excepting HERA and diffractive systems with sufficiently large Pomeron-proton sub-energies.

Available are spectra from meson-baryon processes (compiled in [6]) and for a suitable combination of proton-proton and proton-antiproton processes (compiled in [7]). The incoming proton spectrum at fixed $p_\perp$ (plotted in [8] or [9]) are consistent with a slope of $\alpha_{Transfer} - \alpha_{Pomeron} = -1$ with large error. As the central data points are somewhat on the high side there is a hint of an eventual turnover to a flatter slope. The $p_\perp$-integrated ratio of the incoming baryon and the sea-baryon distribution was given in [10, 11] to be:

$$A_{ISR} = \frac{\rho_{initial\, baryon\, charge}(y)}{\rho_{sea\, baryon\, charge}(y)} = 0.39 \pm 0.05,\ 0.33 \pm 0.05,\ 0.23 \pm 0.05$$

for $y = -0.4$, $y = 0$ and $y = +0.4$[1]. The central derivative of A_{ISR} obtains no contribution from the (symmetric) sea-baryon distribution. Assuming the usual exponential distribution

$$A \propto \exp[(\alpha_{Transfer} - \alpha_{Pomeron})y] \tag{1}$$

the quantity

$$\frac{d/dy\, A_{ISR}}{A_{ISR}}|_{y=0} = \alpha_{Transfer} - \alpha_{Pomeron} = -0.49^{+0.42}_{-0.37} \tag{2}$$

[1] As the data have anyhow a large error the numbers are just taken from the figure 29[10]. The subtraction assumed that the sea-antiproton distributions in proton-antiproton and proton-proton scattering are equal.

just yields the slope[2] . While not in absolute contradiction with a slope around one the indicated value is again considerably less.

New preliminary data come from the H1 experiment at HERA[12]. They observed the initial baryons asymmetry at laboratory rapidities

$$A_{H1} = \frac{\rho_{initial\,baryon\,charge}(y)}{\rho_{sea\,baryon\,charge}(y)} = 0.08 \pm 0.01 \pm 0.025 \tag{3}$$

A simple extrapolation of the ISR value to the larger rapidity difference[3] would have "predicted":

$$A_{H1} = 0.061^{+0.243}_{-0.046} \tag{4}$$

Hence the H1 values lie within the expected range . The required rather flat value of the slope is

$$\alpha_{Transfer} - \alpha_{Pomeron} = -0.4 \pm 0.2$$

The baryon stopping seen in the spectra is related by the Mueller-Kancheli relation to the annihilation cross section. With certain assumptions similar conclusions yielding a steep slope and a possible flattening at higher energies can be drawn from this data [4].

Dual Topological picture There are several Regge-pole contributions for the slowing down of baryons in hadron hadron scattering. The basic philosophy of the Dual Topological models[15] in the classification of such exchanges[16] involves “materializing” or “suppressed” strings. “Materializing” means that the initial color fields are neutralized by a chain of hadronizing qq pairs, “suppressed” means hadron-less neutralization by an exchange of a single quark. It is analogous to the Pomeron and the Reggeon exchange where in addition to a two chain Pomeron a one-chain Reggeon has to be considered. Phenomenologically contributions with various suppressed strings have to be considered as independent and additive. For each suppressed string an extra factor $(\sqrt{1/M_{string}})$ appears and restricts the suppressed contribution to low energies.

For a nuclear exchange one starts with a completely suppressed exchange, i. e. with the square of the quasi-elastic nucleon exchange amplitude

$$\alpha^{III}_{junction} - 1 = 2(\alpha_{Nucleon} - 1) = -2 \tag{5}$$

[2] A similar value was obtained in[2] in a fit which required more assumptions.

[3] It assumes that the sea stays constant. With an increasing sea baryon spectrum the conclusion about the flattening slope would be slightly stronger.

[4] Data on identified annihilation are available only at energies below 20 GeV. The data fall of like a power of roughly $a_{Transfer} - 1 = -1$. In this range the difference in the proton-proton and proton-antiproton cross sections is saturated by annihilation. At high energies this difference in the cross sections turns to a flatter slope of roughly $a_{Transfer} - 1 = -0.5$. The data[13, 14] have smaller errors and the indication of a knee is stronger than in the inclusive ISR distribution. However the interpretation as annihilation process is not clear as mesonic trajectories $(\omega + f_0\ )$ also contribute to $p\bar{p}$ scattering only.

known from elastic backward scattering. Each of the three exchanged valence quarks can now be replaced by a "materializing" string. Corresponding to three, two, one or zero strings there are four contributions with trajectories spaced by one half. At considered energies the first two of these "baryonium" trajectories with two and three hadronizing strings

$$\alpha^0_{junction} - 1 = -0.5,\ \alpha^I_{junction} - 1 = -1.0 \quad (6)$$

will be relevant. They could be responsible for the initially steep (-1.0) and then possible flattening (-0.5) slope observed in the data discussed above.

The value of the final slope is rather uncertain. Even a value of $\alpha^I_{junction} - 1 = 0$ was proposed in the literature[17, 18]. The correspondence to the Odderon gives some support to such a value. Another uncertainty comes from the ω-trajectory. The baryonium exchange has the same quantum numbers as the ω-meson Reggeon. A simple estimate of an additional ω-contribution leads to a too large non-annihilation contribution[18]. One solution is to identify the initial trajectory as a mixture of both contributions was developed in literature[19, 20]. In this way it is possible to identify the turnover in the slope with onset of the sea baryon antibaryon production observed in the inclusive spectrum [9]. The predicted strong correlation between baryon stopping and sea-baryon antibaryon density is not found in the data[10] and we therefore assume here that the mixing if existing is very weak. An alternative solution to the ω-problem will be given below.

Implementation in Dual Parton model based Monte Carlo codes The Dual Parton model was developed for high energies and it has in its present implementation no mesonic Regge-pole exchanges appear in the iterations which determine the cross sections.[5]. Considering just the interplay of local baryonium exchanges within a global Pomeron exchange is straight forward. The factorization among strings allows to ignore the quark string which is common to both trajectories. The transition of the remaining diquark string (baryonium remnant) into an antiquark string (Pomeron remnant) can be implemented in a usual fragmentation scheme by a suitable choice of the splitting function for diquark-diquark, quark-diquark, diquark-quark and quark-quark transitions. It was implemented in most string models e.g. [22, 23, 24] and it is part of the JETSET program (as diquarks or as pop-corn mechanism[25]). Without relying on string factorization leading- and sea-baryon exchanges are also implemented in HIJING/$B\bar{B}$. [26].

[5] To be precise, some Monte Carlo implementations (like DPMJET[5] or PHOJET[21]) include simple Regge exchanges to stay applicable at lower energies. Also if individual chains happen to come out too light to produce partons their parent quarks are annihilated to mimic a Regge-pol exchange as far as the final state is concerned. The neglect of the (flavor moving) Regge contribution is questionable in heavy ion scattering when multiple scattering processes are common and sub-energies of the involved constituents are often quite low.

3 Baryon enhancement in dense heavy ion scattering

Concepts for slowing-down initial baryons There are a few completely conventional mechanisms of baryon transfer and central baryon production for multiple scattering processes in string models[6]. They were investigated numerically[5], they are helpful in some regions but not enough to explain the large stopping in heavy ion scattering.

To understand the data it seems necessary to include interplay of string if they get sufficiently dense in transverse space. It was proposed that there are new special strings[31, 32]. In contrast, we shall maintain here the general factorization hypothesis between initial scattering and the final hadronization within standard strings. We will just consider a more complex string structure.

The usual Pomeron exchange in the Dual Parton model leaves a quark and a diquark for the string ends. Diquarks are no special entities and multiple scattering processes have no reason not to split them in a suitable conventional two Pomeron interaction. It is natural to expect that diquark break-ups considerably slow down the baryons evolving. The probability for such an essentially un-absorbed[33] process is[34]:

$$[break\ up]/[no\ break\ up] \propto [cut\ Pomeron\ number] - 1 \tag{7}$$

As required by the experimentally observed slowdown this is a drastic effect for heavy ion scattering while for hadron-hadron scattering multiple scattering are sufficiently rare (especially at energies studied in detail) to preserve the known hadron-hadron phenomenology. How such processes are affected was considered numerically in [5] and no manifestly disturbing effects were found.

We emphasize here that the behavior of the baryon quantum number slowed down by such a break-up is not trivial. In topological models the baryon contains Y-shaped color electric fluxes. Two Pomerons intercepting two different branches will leave two "free" valence quarks and a valence quark connected with the vortex line with the velocity of initial Baryon to form the end of the strings. Nothing is a priory known about the energy distribution of such quarks with vortex lines in the structure function. A simple identification with the attached quark distributions[36] somewhat in the spirit of color evaporation models has no basis in a dual framework.

[6] Besides the purely kinematic "attenuation" effect[27] in multiple scattering events, the initial baryon can be slowed down if a secondary Pomeron exchange picks up a valence quark and leave the diquark with one (typically slower) sea quark[28]. An obvious mechanism of central baryon production involves sea diquark-antidiquark pairs. Except for a limited number of valence partons, strings have to connect to sea partons which can also be diquark-antidiquark pairs[29]. It is known from the analysis of the transverse momenta, i.e. of $< p_\perp >_{n_{\{charged\}}}$ [30], that the partons of the string ends come from a harder (naturally more $SU(3)$ -symmetric) initial phase. Multiple additional sea quarks are therefore helpful in the understanding of the strangeness enhancement.

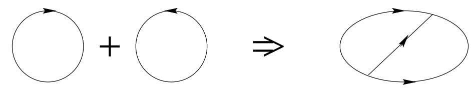

Figure 1: The joining of two cylinders with opposite orientation

Special baryon transfers in the Topological model For a more detailed description of the slowing down we turn to the Dual Topological model[16] introduced in section 2. A discussion of baryon transfers in such a framework was recently given by Kharzeev[37]. We will here emphasize topological aspects.

In topological models a Pomeron exchange corresponds to a cylinder of in a certain way arranged gluon fields connecting the two scattering hadrons. If one considers an arbitrary plane intersecting this exchange (say at a fixed exchange-channel time) the intersection of the cylinder is topologically equivalent to a circle. More specifically in topological models amplitudes with clockwise respectively anticlockwise orientation have to be added or subtracted depending on the charge parity. The cylinders or the circles therefore come with two orientations. This distinction is usually not very important as it is always possible to attach hadrons in a matching way; except for C-parity conservation no special restrictions result.

Pomerons have a transverse extent and if they get close in transverse space they should interact. Hadronic interaction is sufficiently strong to be largely determined by geometry. It is therefore reasonable to expect that the coupling does not strongly depend on the orientation as long as there is no mechanism of suppression.

The two distinct configurations lead to different interactions. Two Pomerons with the same orientation can if they touch (starting locally at one point in the exchange-channel time) shorten their circumference and form a single circle. This then corresponds to the usual triple Pomeron coupling experimentally well known from diffractive processes.

For two Pomerons with opposite orientation the situation is more complicated. Like for soap bubbles the two surfaces which get in contact can merge and form a single membrane. The joining inverts the orientation of the membrane. On the intersecting plane one now obtains – instead of the single circle – three lines originating in a vortex point and ending in an anti-vortex point as shown in figure 1 . Lacking a topological name for the three dimensional object the term membraned cylinder will be used in the following.

How do this membraned cylinder contribute to particle production? Similar to the triple Pomeron case there are three different ways to cut through a membraned cylinder. The cut which also intersects the membrane has vortex lines on both sides. They present a topological description of the baryon transfers considered in this paper. Cuts which intersect only two sheets contribute as an absorptive reduction of the two string contribution. Their negative contributions make the understanding of total cross sections not straightforward. It is possible that the membraned cylinder exchange has a vanishing or negative

imaginary part. The ω-exchange could indeed dominate the difference in the cross section while the contribution of the three string cut of the membraned cylinder could be more or less compensated by its negative two string cut. In the final states the annihilation process can be observed while the one string ω-exchange contribution and the two string membraned cylinder reduction is hidden resp. contained in the usual two string contribution.

The identification with the Odderon Even though QCD cannot presently be used to calculate soft processes the typical absence of a abrupt changes in experimental distributions indicates that there is no discontinuous transition between soft and hard reactions both formulated on a partonic level. This provides the hope that hard processes can be used as a guide and that soft processes can be parameterized as an extrapolation of calculable hard processes.

The well known example is the connection between soft and hard Pomerons. To identify the hard partner of the soft Pomeron we first observe that the simplest representation of a Pomeron in PQCD involves the exchange of two gluons. As spin one particles exchanged gluons introduce no energy dependence and two gluons can form color singlets with the required positive charge parity. Following this concept it can be shown[38] that a generalization of such an exchange gives in a rather well defined approximation the dominant contribution at very high energies. It involves a ladder of Reggeized gluons and is called the "hard" or BFKL Pomeron. Topologically in a leading $1/N$ -expansion gluons can be represented by pairs of color lines drawn without crossing on a geometrical structure representing the considered contribution to the amplitude. In this expansion the leading structure of a BFKL Pomeron corresponds to a cylinder with the two basic gluons exchanged on opposites sides parallel to the axis. As they are in a color singlet state their matching color lines can be connected in front of the cylinder as shown in Fig.2a . Analogously the outer lines can be connected on the back of the cylinder.

Going back to the soft regime the basic assumption in topological models is that the $1/N$ -expansion stays valid [7] and that the soft Pomeron therefore maintains its cylindrical structure. If cut, soft and hard Pomerons therefore lead to similar two string final states. As difference it remains that the slope of the soft Pomeron is just shifted downward roughly a third of a unit.

Can one find a similar connection for the membraned cylinder? The simplest representation spanning such a structure involves at least three gluons, one on each sheet again parallel to the axis. Any gluon connecting these exchanges has then to pass through a vortex line. In the $1/N$ expansion this means that the color lines have to cross like in Fig. 2b[8]. A color singlet of three gluons

[7] The $1/N$ expansion is in principle destroyed in the soft limit by huge combinatorial factors if the number of considered gluons increases. The hope is that preconfinement effects and a typical correlation of spatial coordinates and momenta create a situation where the (stray) long distance gluon exchanges which is responsible for the disturbing combinatorial factors cancel as color and anti-color lines are too closely neighbored when seen from a distance.

[8] In spite of the crossing of color lines it is a leading contribution in the $1/N$ expansion. The introduction of baryons in this expansion has to be done with care[16]. For a given N a

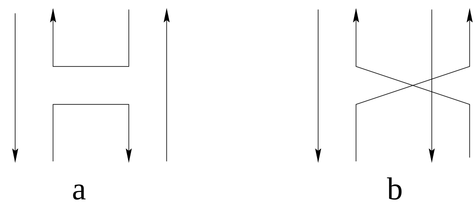

Figure 2: The color lines of a gluon link between two exchanged gluons

can have the quantum numbers of a Pomeron or an Odderon[39]. There is a simple topological property of the Odderon. A single gluon connection of type Fig.2a would project the color structure of the pair to that of a single gluon (or singlet) and the exchange would have to correspond to a Pomeron-like effective two gluon contribution. The Odderon will therefore have to involve only crossed connections shown in Fig.2b. Hence it has the topology of the membraned cylinder.

The identification with the Odderon fixes the C-parity of the membraned cylinder and a twisted membraned cylinder will have to contribute to pp scattering at least asymptotically equally and with opposite sign as in $p\overline{p}$ scattering. For the twisted exchange only one type of cut exists, it will always involve a two step transition from a vortex-antivortex piece to a two string piece with both vortices on one side and to an antivortex-vortex piece. Depending on its sign it will absorb or add to the contribution in which the two string part is replaced by a usual Pomeron cut. In diffraction the situation is more complicated. As the imaginary (and real) part of the Pomeron-Pomeron-Odderon contribution has to vanish, the sum over all contributions will cancel. As some cuts have a negative sign no restriction on individual terms in the sum result.

In the same QCD approximation as the "hard" Pomeron the properties of a "hard" or BKP Odderon[40] were calculated. The consensus is that the corrections to the initial gluon intercept are smaller than for the Pomeron and the intercept is rather firmly predicted to be close to 0.96[41]. There is a mismatch between this hard Odderon intercept and the (with large error) experimentally observed soft value again by about a third of a unit.

4 Experimental consequences of membraned cylinder exchanges.

Odderon in heavy ion scattering In heavy ion scattering where the Pomerons are dense in transverse space they can join and form a Pomeron or a membraned cylinder. This helps with the problem of unphysical high string densities. The individual strings pairs are no longer independent but the gen-

membraned cylinder would actually require a structure with $N-2$ membranes with N gluons so that suppression ($1/N$) associated with the crossed exchange would be compensated by the $N-1$ connection choices.

eral picture of particle production in separate universal strings survives. There should be a considerable probability of membraned cylinder exchanges growing proportional to the density:

$$\frac{[number\, of\; membraned\, cylinders]}{[Pomeron\, number]} \propto \frac{[Pomeron\, number][Pomeron\, radius]^2}{[nucleus\, radius]^2} \tag{8}$$

The transition from a Pomeron pair to the centrally cut membraned-cylinder requires a baryon antibaryon pair production. Between a proton and a Pomeron the cut membraned-cylinder is a very efficient mechanism of baryon stopping.

As the slope is not well determined it is hard to obtain really reliable quantitative statements which can be tested with convincing results in heavy ion scattering. There is however a very specific qualitative prediction which should be testable.

The backward peak in diffraction and possibly in electro production
We consider a diffractive system whose mass exceeds ISR energies. Usually the diffractively produced particles will originate in two strings of a cut Pomeron and the baryon charge will stay on the side of the initial proton. As usual there might be some migration to the center with a slope eventually corresponding to the difference of the Odderon and the Pomeron trajectory.

To accept the high soft Odderon slope suggested by the data on baryon transfers it is necessary to require a clear suppression from the coupling constants. It is quite natural to assume that the transition between a baryon exchange (cut membraned cylinder) and non baryon exchange (cut Pomeron) has no large overlap and a relatively small coupling. No such suppression is expected at a two Pomeron vertex. This has a direct consequence in rapidity space. At a certain distance it should be more favorable for an Odderon to span the total diffractive region and to utilize in this way the more favorable coupling to the two Pomerons. In consequence the initial baryon will end up exactly at the end of the string. In the usual presentation of rapidity plots this might be smeared out if different masses of diffractive system are included. This problem can be solved if one plots the rapidity distribution of initial baryons in relation to the inner end of the diffractive region, i.e. as function of

$$y_{\{Pomeron\}} = y_{\{CMS\}} - \ln \frac{m\sqrt{s}}{M(diffr.)}$$

The expectation is that a small backward peak should then be visible. To substantiate this we show in Figure 3 the result of a calculation with the PHOJET Monte Carlo code[21] with standard parameters. To select diffractive events a lower cutoff of $x_F = 0.95$ was used. PHOJET contains diquark exchanges and yields reasonable baryon spectra in the forward region. To obtain the postulated backward peak we just mix a suitable sample of such events. These special events are obtained by suitably inverting the rapidity distribution of usual events. For this inverted contribution the diquark exchanges were disabled to ensure that the backward baryon ends up on the last rank.

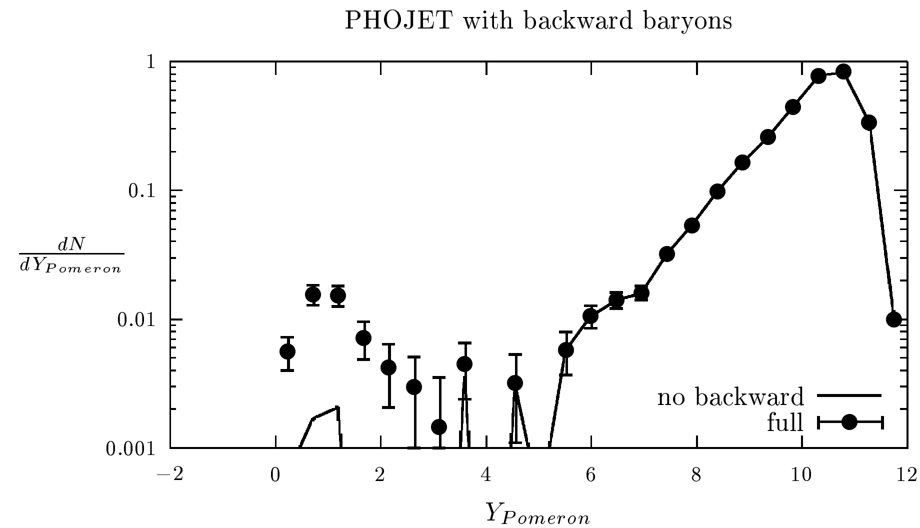

Figure 3: The incoming proton spectrum for diffractive events with a mass of 300 GeV generated with a modified PHOJET generator for pp-scattering of 1.8 TeV.

For a diffractive system with a mass of 300 GeV the suppression from the slope is of the order of a factor of 10. To account for the unknown ratio of coupling constants and for uncertainties connected with the somewhat simple implementation we add a factor 6 and took 30 million normal events and 0.5 million inverted ones. It is important to stress that this is not an absolute prediction but an illustration of the reasonably expected effect. No effort was made to explicitely include the turnover in the baryon spectra discussed in section 2.

It is clear that suitable diffractive events should be available at the TEVATRON and that such data could be decisive. Similar measurements might also be possible at HERA. It is likely in the scattering of a virtual photon on a proton that the photon does not prefer a fixed topology and the coupling to an Odderon is also not disfavored. In this case the same backward peak might be observable in non diffractive ep data.

5 Conclusion

The present paper wants to encourage the measurement of the initial baryon distribution in high mass diffractive systems. The known initial baryon distribution suggests that there is a contribution to the exchange which is most strongly suppressed by its coupling and not by its slope. It is argued that this should not be the case in diffractive events and in consequence there should be an observable tiny backward peak in the initial baryon distribution in the diffractive

system. The prediction is important as it has manifest consequences for heavy ion processes, where it would be a strong mechanism for central baryon production and for the transport of initial baryons to the central and opposite region. It might also clarify the role of the Odderon.

Acknowledgments

I thank Lech Szymanowski and L. Lukaszuk for discussion regarding the Odderon. I am indebted to J. Ranft and H. Anlauf for reading the manuscript and many useful comments. I also acknowledge his help in running the PHOJET code to obtain Figure 3. The work is based on work done with Patrick Aurenche.

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